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WATER TUNNEL TESTS OF SUBMERSIBLE MODELS.(U)
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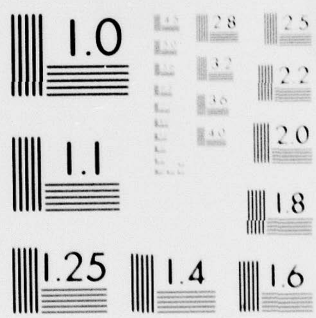

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Two submersible models were tested in a water/wind tunnel running in the water mode. The results of these tests were compared with data generated on larger models which were tested in the 12-foot Pressure Wind Tunnel (PWT) at NASA/Ames Research Center. It was concluded that the test medium had negligible effect on the results. Differences were found between the two sets of data only at the higher angles of attack. These were considered to be due to differences in tunnel Reynolds number.

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INTRODUCTION

With support from the Naval Coastal Systems Laboratory (Contract N61339-76-C-0076) Neilson Engineering and Research, Inc. (NEAR Inc.) has constructed a number of semi-empirical methods for predicting the hydrodynamic characteristics of submersible vehicles[(1)]. The data necessary for method construction were generated in the 12-foot pressure wind tunnel (PWT) at Ames Research Center (ARC). The test models were specially built by NEAR Inc.

Since the testing was done in air, and submersible vehicles operate in water, the effect of the test medium on the results was questioned. Classical fluid-dynamic theory shows that the test medium will have no effect on the test results provided the test Reynolds number is held constant. Despite this, however, it was considered worthwhile to devote a small portion of the contract funds to a limited investigation of the effect of the test medium. Accordingly, a model was constructed, geometrically identical to one of the typical wind tunnel models, but of 1/3.5th the size and tested in the NEAR water tunnel. It was not possible to test a wind-tunnel-sized model because of water tunnel size limitations.

DESCRIPTION OF WATER/WIND TUNNEL

The water/wind tunnel (WWT) (Figure 1) is a highly flexible facility in which models can be tested in two media. The basic test section is all plexiglass and glass for 100 percent visibility. It is 14 by 20 by 72 inches long (35.6 x 51 x 183 cm). The nozzle, test section and diffuser can be rotated as a unit, making the test section either 14 or 20 inches high. The latter was used in the reported tests. Flow speed ranges are 0-20 ft/sec (0-6.1 m/sec) in water and 0-200 ft/sec (0-61 m/sec) in air. The nozzle has a contraction ratio of 8:1 and there are

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[(1)] Naval Coastal Systems Center Technical Memorandum 238-78, *Methods for Predicting Submersible Hydrodynamic Characteristics*, prepared by Neilson Engineering and Research, Inc., July 1978.

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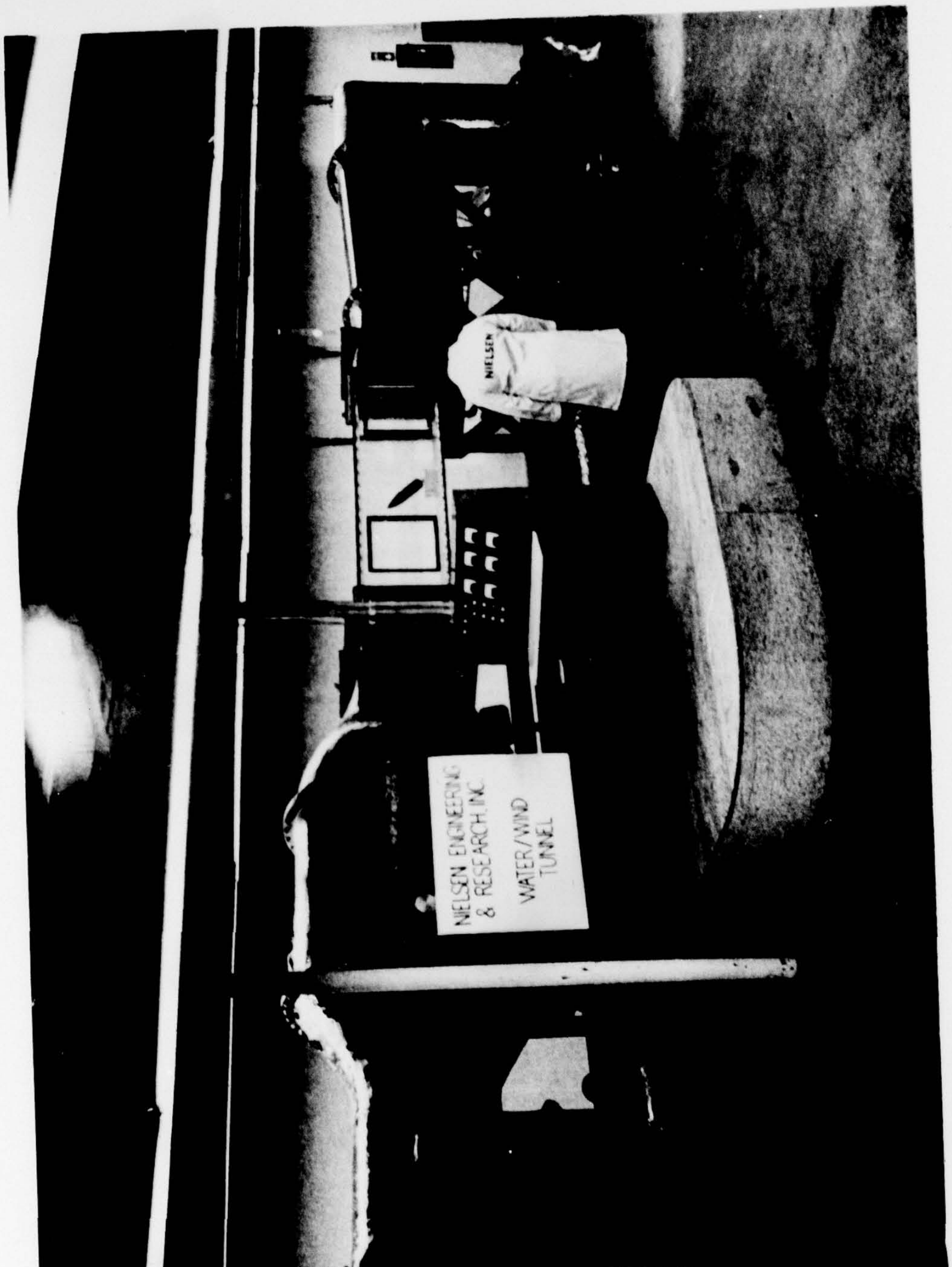

FIGURE 1. WATER/WIND TUNNEL

four turbulence-damping screens in the settling chamber. Flow angularity in the test section is ±0.2 degrees and the maximum velocity deviation is ±0.2 percent.

The tunnel has been used for conventional force and moment testing, plus flow visualization studies in the water mode using dye and bubbles. It has also been used for Laser Doppler Velocimeter measurements of body vortices.

During the present tests the tunnel was run in the water mode near the highest speed available to maximize test Reynolds number at roughly 2×10^6 per foot.

MODELS

The models tested were designated N2C2B2 and N2C2B2T11$_M$, corresponding to the notation used for wind tunnel testing as described in the final report on methods construction[1]. The main features of the models were: an ellipsoidal nose of one body diameter length; a cylindrical center section of four body diameters length; a conical base of two body diameters length; a set of four cruciform tails with an aspect ratio of 1.0, taper ratio 0.5, and a body radius/tail half-span = 1.4. The addition of the cruciform tails constituted the only difference between the two models. N2C2B2T11$_M$ is shown in Figure 2. Body diameter

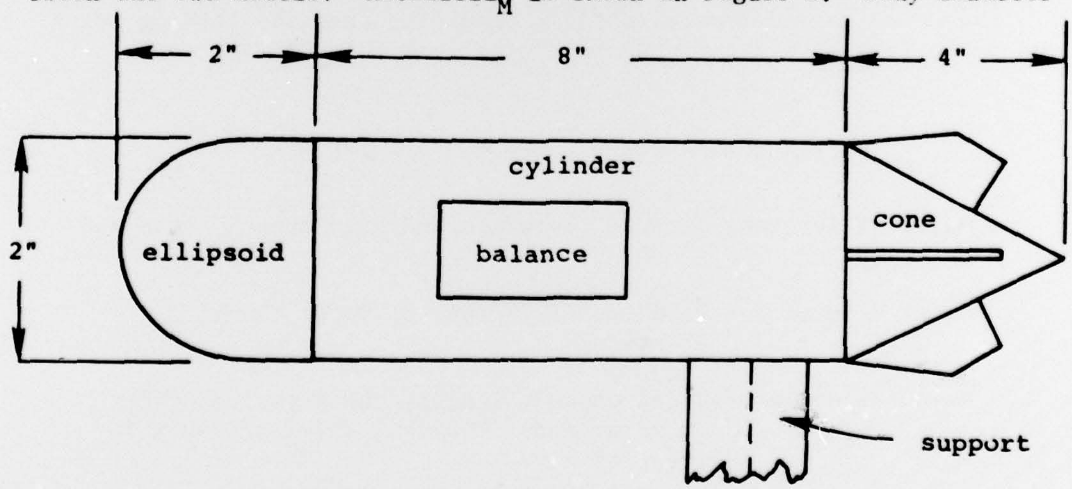

FIGURE 2. MODEL N2B2C2T11$_M$

(1) ibid.

was 2 inches, as opposed to the wind tunnel model, whose diameter was 7 inches. The models were supported in the water tunnel by means of a vertical strut of faired double wedge section located just forward of the tail leading edge.

TESTS

The tests were run at a nominal water velocity of 20 ft/sec. This gave a Reynolds number, based on body length, of 2.12×10^6 (the maximum wind tunnel Reynolds number for the same model was 60×10^6). The model pitch angle of attack was varied from -3 to +15 degrees which corresponded to the wind tunnel tests. Tails were undeflected. Figure 3 shows the model $N2C2B2T11_M$ in the water tunnel. During the tests, a positive angle of attack was taken as that which placed the strut on the lee-side of the body to minimize interference.

Five components of force and moment were read from the strain gauge balance during the tests; normal force, pitching moment, side force, yawing moment, and rolling moment. All except the first two of these were negligible, as would be expected. Flow visualization studies were made to complement the balance data. Air bubbles were introduced into the water upstream of the model. Figures 4 and 5 show typical results from these investigations. The quantitative results indicated that the flow over the base remained attached (as was also found in the wind tunnel). They also showed strong vortices emanating from the leading edges of the tails. No cavitation was observed at any point in the tests.

DIFFERENCES BETWEEN WATER AND AIR TESTS

The major differences between the water and wind tunnel tests and models were:

1. Model diameter - Wind tunnel, 7 inches; water tunnel 2 inches.

2. Reynolds number - Based on body length, the Reynolds number in water and air were 2×10^6 and 60×10^6, respectively.

3. Tunnel blockage - Based on model frontal area at zero angle of attack, blockages expressed as percent of working section area were:
   water, 1.12 percent
   wind, 0.22 percent

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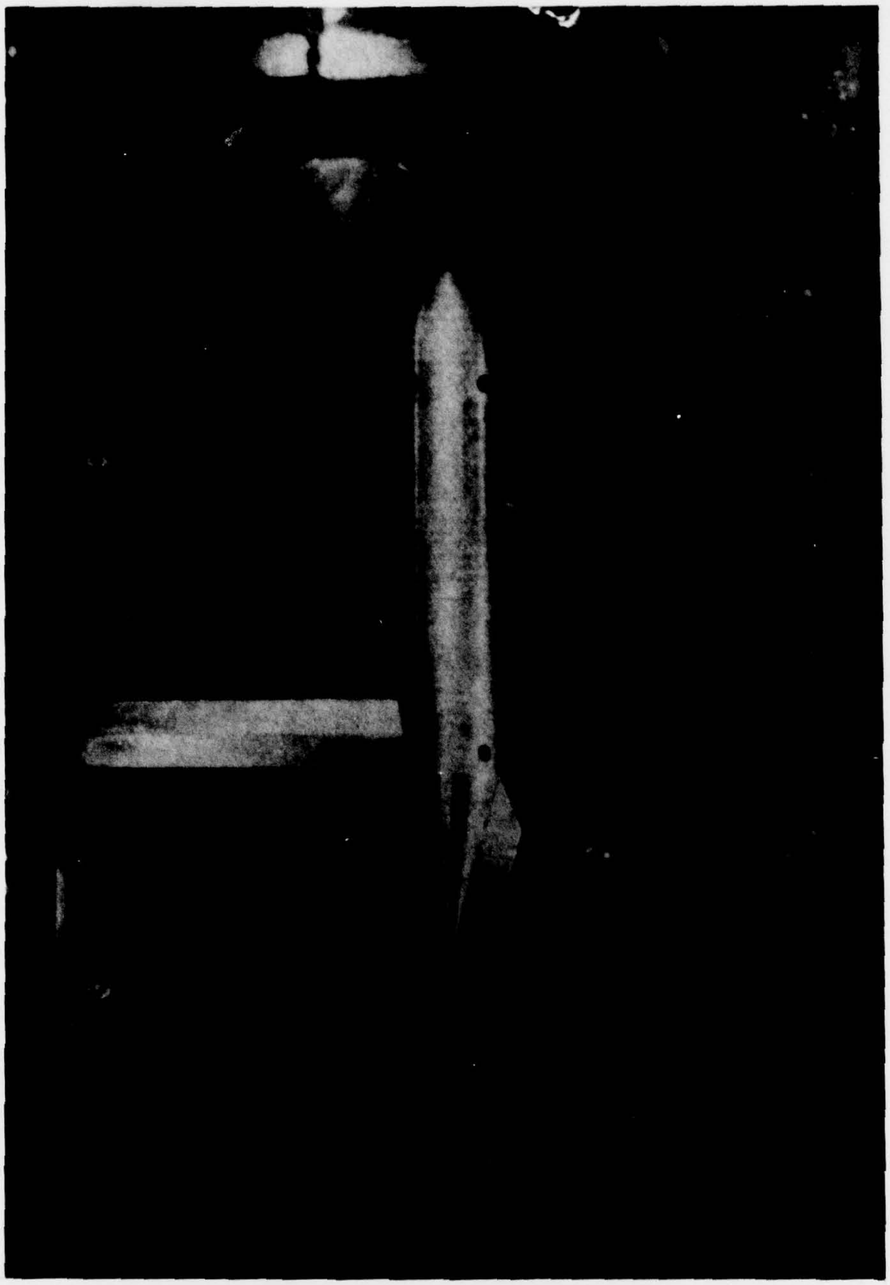

FIGURE 3. N2C2B2T11$_M$ IN WATER TUNNEL, $\alpha = 0^\circ$

FIGURE 4. AIR BUBBLE PATTERN ON BASE SHOWING NO SEPARATION, $\alpha = 0^{\circ}$

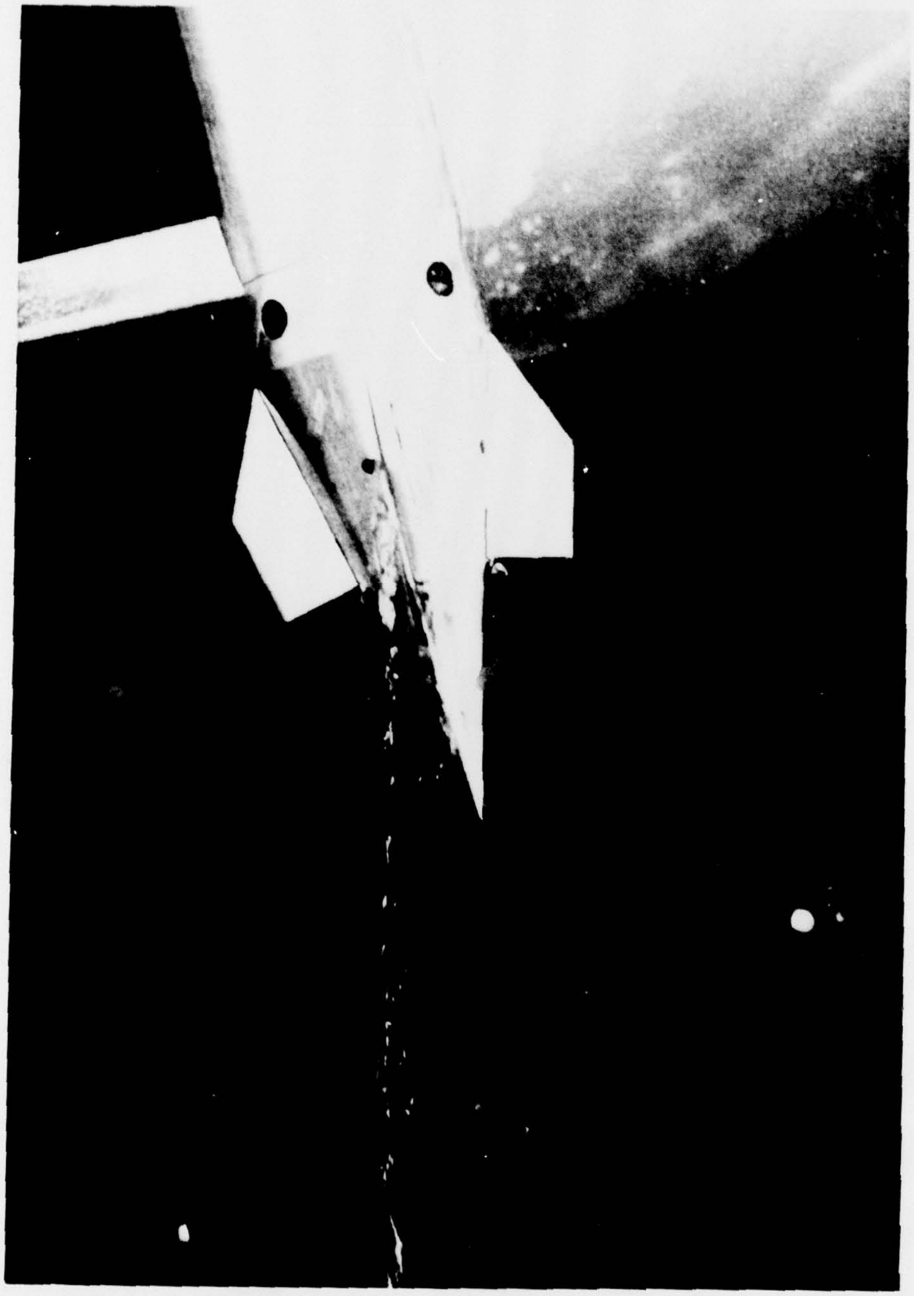

FIGURE 5. AIR BUBBLE PATTERN SHOWING TAIL VORTEX, $\alpha = 15^{\circ}$
(POSITIVE ANGLE OF ATTACK)

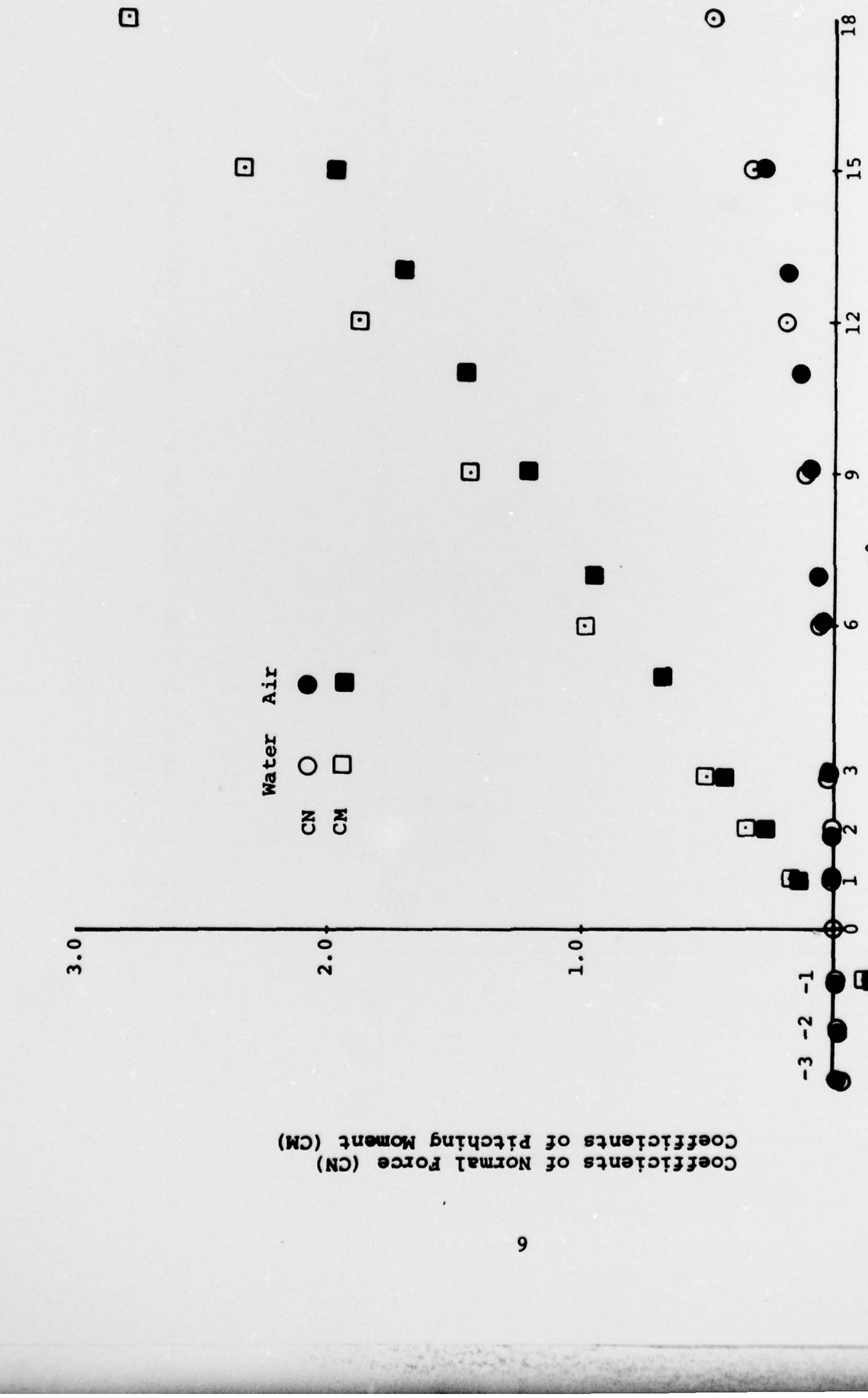

FIGURE 6. COMPARISON BETWEEN WATER AND WIND TUNNEL TESTS, N2C2B2

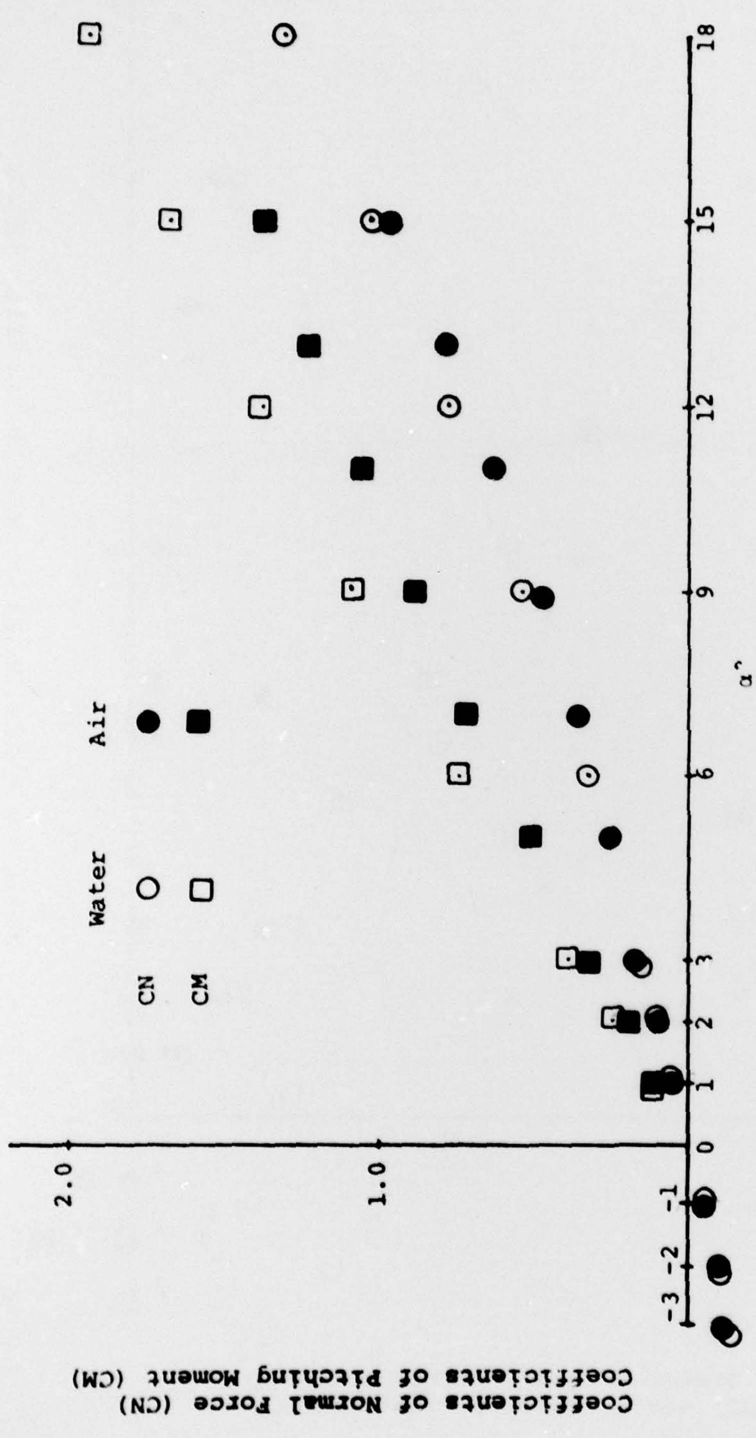

FIGURE 7. COMPARISON BETWEEN WATER AND WIND TUNNEL TESTS, $N2C2B2T11_M$

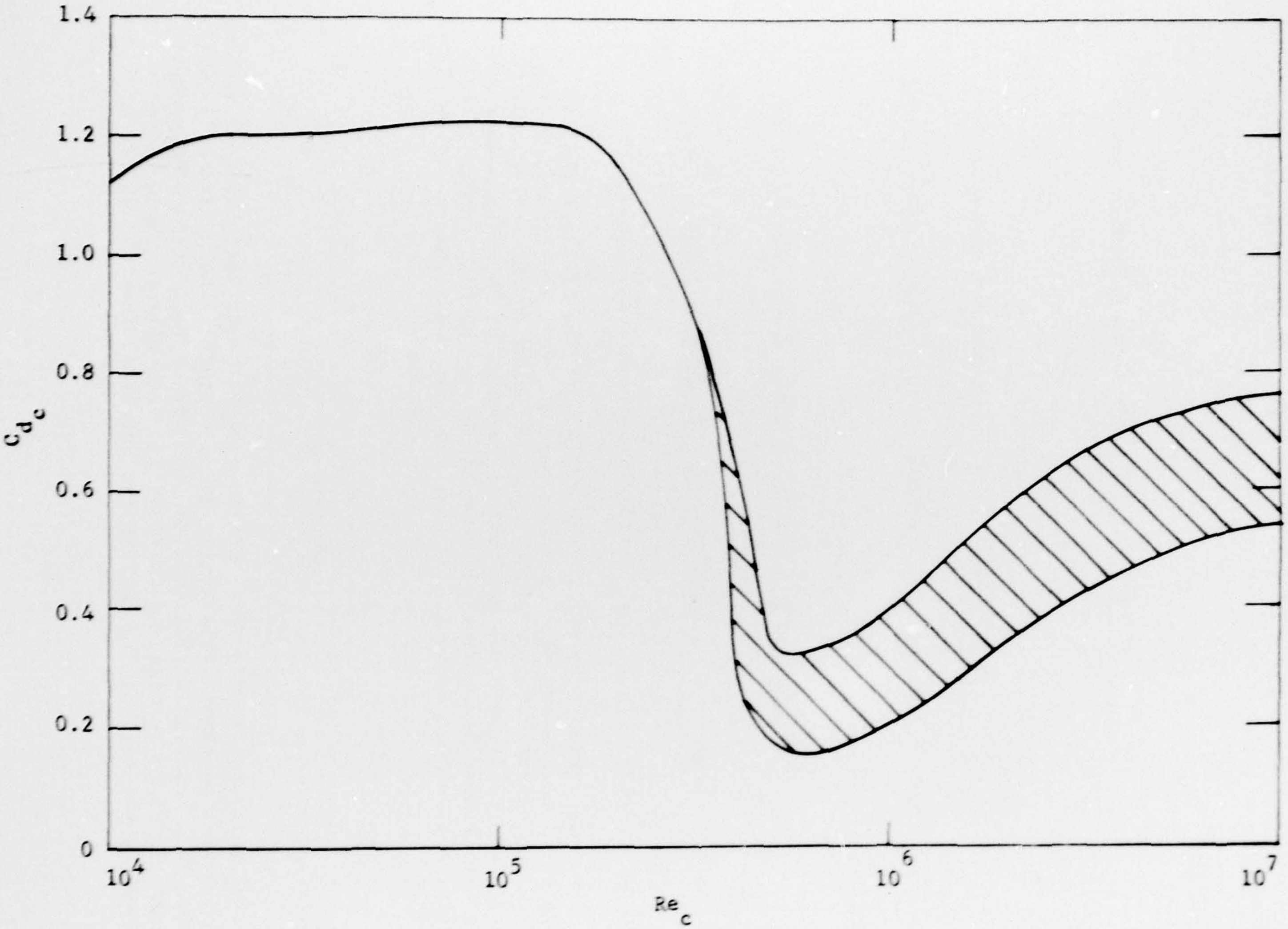

FIGURE 8. VARIATION OF CROSSFLOW DRAG WITH CROSSFLOW REYNOLDS NUMBER

of pressure on the other hand are very close together; e.g., at 15 degrees:

Body Alone

$$\frac{x_{cp}}{d}_{wind} = \frac{1.965}{0.275} = 7.15 \quad \text{forward of balance center}$$

$$\frac{x_{cp}}{d} = \frac{C_M}{C_N}$$

$$\frac{x_{cp}}{d}_{water} = \frac{2.339}{0.322} = 7.26 \quad \text{forward of balance center,}$$

which is a center of pressure difference of only about 1/10th caliber.

Body Tail

$$\frac{x_{cp}}{d}_{wind} = \frac{1.363}{0.974} = 1.40 \quad \text{forward of balance center}$$

$$\frac{x_{cp}}{d}_{water} = \frac{1.680}{1.032} = 1.63 \quad \text{forward of balance center,}$$

which is somewhat larger, but is still less than 1/4 caliber.

The implication from these results is that the axial extents of separated crossflow are equal in each case but that the crossflow drag coefficient varies with crossflow Reynolds number in the well-known manner. Hence, it is concluded that the effects of Reynolds number and other differences can be invoked to account for the differences in test results. It is further concluded that the test medium has negligible effect.

CONCLUSIONS

The major conclusion from this investigation is that the test medium has no effect on submersible static data, whether it be generated in water or air. This has significant implications for configuration development. However, it is to be expected that dynamic data will continue to be affected by the test medium through its effect on inertia quantities.

NOMENCLATURE

C_{d_c}	crossflow drag per unit length of body
C_M	pitching moment coefficient, M/qS_Rd
C_N	normal force coefficient, N/qS_R
d	body cylindrical portion diamter, wind tunnel, 7 inches, water tunnel, 2 inches
M	pitching moment
N	normal force
q	free stream dynamic pressure
Re	Reynolds number per foot
Re_c	Reynolds number based on body crossflow quantities $= dV_\infty \sin\alpha/\nu$
S_R	body cylindrical portion cross-sectional area
V	free-stream velocity
α	angle of attack
ν	kinematic viscosity

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